

SUPPLEMENTARY INFORMATION

Electron microprobe analyses and X-ray maps

Major element compositions of olivine from B3N were taken from published analyses in Schiano et al., 1995 and Eiler et al., 2007; the latter were measured using a JEOL 733 electron microprobe at Caltech. New measurements of minerals from samples S500-5b, 98M1, R215-7b and San Carlos olivine were made in the Caltech Analytical Facility, using a Joel JXA-8200 'superprobe'. Analyses were made with a 15 KeV, 25 nA electron beam, defocused to a 10 μm spot. Analyses were standardized to measurements of synthetic forsterite (for Si and Mg), Fayalite (Fe), Mn-olivine (for Mn), Ni-olivine (for Ni), chromium oxide (for Cr) and anorthite (for Al and Ca). Al and Cr were not analyzed in olivine all sessions. Analyses of Na and Ti in clinopyroxene were standardized by analysis of Amelia Albite and a natural rutile, respectively. All data are recalculated as weight per cent on an oxide basis (assuming all Mg, Mn, Fe, Ca and Ni are divalent, Cr and Al are trivalent and Si and Ti are tetravalent and Na is monovalent). Table SI-1 present these new electron microprobe measurements. X-ray maps of P abundance were made using this same instrument, using methods detailed in Milman-Barris et al., 2008.

Ion microprobe analyses

Three different sets of Ion microprobe analyses were made using three different instruments over the course of this study:

CAMECA IMS 1280: Oxygen-isotope analyses of natural samples were made using the

CAMECA IMS-1280 ion microprobe at the University of Wisconsin. Analytical

conditions closely resembled those previously described by Kita et al., 2004 and Eiler et al. 2007. Briefly, the sample was bombarded with a focused, $\sim 5\text{-}20\text{ }\mu\text{m}$, primary beam of $^{133}\text{Cs}^+$ ions with a 20 keV impact energy and between $\sim 1\text{ nA}$ and $\sim 5\text{ nA}$ ion current delivered to the sample surface. An electron flood gun was used for charge compensation. Secondary O^- ions were extracted, accelerated by 10 keV, and both ^{16}O and ^{18}O were simultaneously detected using two faraday cup collectors. The mass resolving power was ~ 2500 , enough to separate hydride interferences on ^{18}O . Each analysis consisted of 20 cycles of 4 seconds each; the external precision of the $^{18}\text{O}/^{16}\text{O}$ ratio was typically between 0.05 and 0.15 ‰, 1 s.e.

All analyses of olivine were standardized to the average value for concurrently analyzed San Carlos olivine standard (assumed to have a $\delta^{18}\text{O}$ of 5.35 ‰ vs. SMOW, based on fluorination measurements). For each analytical session, an instrumental mass fractionation ($\alpha_{\text{imf}} = ^{18}\text{O}/^{16}\text{O}_{\text{observed}}/^{18}\text{O}/^{16}\text{O}_{\text{true}}$) was calculated from these standard data, and then applied to unknown olivines (i.e., $^{18}\text{O}/^{16}\text{O}_{\text{true}} = ^{18}\text{O}/^{16}\text{O}_{\text{observed}}/\alpha_{\text{imf}}$). Analyses of 98M1 clinopyroxene were standardized similarly, but the α_{imf} accounted for matrix effects by assuming a parabolic relationship between ($\alpha_{\text{imf}}^{\text{pyroxene}}/\alpha_{\text{imf}}^{\text{olivine}}$) and the molar Ca content of pyroxene (following the algorithm described by Kita et al., 2009). This matrix effect correction was on the order of 2 ‰ for the pyroxenes examined in this study.

CAMECA ims-7f geo: Oxygen isotope analyses of olivines and glasses in synthetic samples, MPDA-26 and MPDA-32 were made using the CAMECA ims-7f geo at the Caltech Microanalysis Center. The sample was bombarded with a focused, $\sim 20\text{ }\mu\text{m}$, primary

beam of $^{133}\text{Cs}^+$ ions with a 20 keV impact energy and ~ 2 nA ion current delivered to the sample surface. An electron flood gun was used for charge compensation. Secondary O^- ions were extracted, accelerated by 10 keV, and $^{16}\text{O}^-$ and $^{18}\text{O}^-$ were alternatively detected using a 'psuedo-multi-collecting' algorithm and two separate faraday cup collectors (one for ^{16}O and one for ^{18}O). The mass resolving power was ~ 2000 (sufficient for separating hydride interferences). Each analysis consisted of 20 cycles, each of which included 1 second counting ^{16}O and 4 seconds counting ^{18}O . Typical ^{16}O count rates were $\sim 1 \times 10^9$ cps. The external precision of the $^{18}\text{O}/^{16}\text{O}$ ratio was typically 0.2 ‰, 1s.e. An unpublished study of oxygen isotope analyses in standard olivines using the Caltech ims-7f-Geo indicates that, as for the CAMECA ims-1280, under these conditions there are negligible matrix effects among olivines over the range of olivine compositions in the MPDA synthetic samples. All results are normalized to an average value of 0 ‰ for each phase (i.e., glass or olivine) in each sample (MPDA-26 or MPDA-32).

CAMECA NanoSIMS-50L: Semi-quantitative (i.e., standardless measurements of relative concentration) of P in olivine were made on the CAMECA nanoSIMS-50L at the Caltech Microanalysis Center. The sample was bombarded with a focused, ~ 0.5 μm diameter, primary beam of $^{133}\text{Cs}^+$ ions with a 16 keV impact energy and ~ 10 pA ion current delivered to the sample surface. An electron flood gun was used for charge compensation. Secondary ions were extracted, accelerated by 8 keV, and $^{31}\text{P}^-$ and $^{30}\text{Si}^-$ were simultaneously detected using two electron multipliers. An electronically gated dead time of 44 ns was imposed on both collectors. The mass resolving power was nominally ~ 5000 (sufficient for removing hydride interferences). Each analysis consisted of 500 cycles of 0.42 seconds each. Typical $^{30}\text{Si}^-$ count rates were $\sim 7 \times 10^4$ cps.

The external precision of the $^{31}\text{P}/^{30}\text{Si}$ ratio was typically 0.5 %, 1s.e. Table 5 of the main text reports the measured ratios, corrected for dead time and dark noise. Though we have not attempted to develop a rigorous standardization of the $^{31}\text{P}/^{30}\text{Si}$ ratio for these analytical conditions, for future reference we note that concurrently analyzed San Carlos olivine yielded an average ratio of 7×10^{-4} ($N = 4$). San Carlos olivine has been measured to have a P content of 0.012 ± 0.005 , as wt. % P_2O_5 . If this proportionality extends to the higher P concentrations of our analyzed samples, we would infer that the data range in Table 5 corresponds to 0.043 to 0.327 wt. % P_2O_5 .